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Research paper

Fluid-structure interactions of variable span wings in low Reynold flows

Hafiz Salleh [1] *, Sanisah BT. Sahrin [1], Mohammad Hanafi Bin Azmi [1], S. A. Khan [1]

[1] Department of Mechanical Engineering, Kulliyyah of Engineering, International Islamic University Malaysia
**Corresponding author E-mail: sakhan@iium.edu.my*

Abstract

Numerical method is one of the method which is applied to study the aerodynamics of static variable span morphing wing and to evaluate flow structure over the wing surface (especially leading edge) at different low reynolds number/flow. The numerical result of lift coefficient vs span increment (pencentage) is validated with experimental result from previous study. Effect of the change of wingspan on low Reynold number/flows is investigated for the wing lift coefficient, and aerodynamics efficiency. Some contour results including pressure contour is observed. The pressure contour along wingspan from each case is figured out.

Keywords: *Morphing Wing; Variable Span Wing; Low Reynold.*

1. Introduction

Aircraft is a study of birds' motion from the basic; how the birds move and how they flap and control their wings during take-off, flying and landing (Refer Figure 1.1). This study tends to make people try to fly and then create an aircraft with flapping wings mechanism, but lastly failed since the flapping movement produces the unbalance on the aircraft. According to study, the movement of birds' wings is crucial depends on the condition or purpose. Because of this, the morphing concept is introduced.

Morphing is a smooth transformation of one image and animations into another through a seamless transition. Most often it is used to depict one person turning into another technological means or as part of a fantasy or surreal sequence (Wikipedia). According to Prabhakar, Prazenica and Gudmundsson (2015) [2], they define morphing aircraft as change of flight configuration in order to maximize its function for different conditions. Basically, during take-off, birds will sweep back and shorten their wings (span wings) and start to increase their wings when they are in sky (cruise), and then shorten back their wings when they are going to touch down. This is important to accommodate drag and other disturbances.

Fig. 1.1: Bird Flying Movement.

Previously study created the almost perfect mechanisms and structures with brilliant materials that can let bio-mimetic change to aircraft. Until now (2010), the design target just on constant attempt for overall flight performance, new approaches design and upgrade multi-function of design (Mestrinho, Felicio, Santos & Gamboa, 2010) [4].

The first idea of flight comes from the observation of how birds fly in sky, especially on how they use their wings in different situations. First analogy, engineers see how the birds flap their wings to lift up their body, and then small aircraft with flapping wings was created, but failed. This tends engineers to do some deep researches on this problem and then aircraft with fixed wings and powered engines was created successfully.

Since the change of birds' wings during take-off, flying and landing is much crucial, the morphing idea was introduced. This is to make sure that the aircraft created can perform at optimum. We can see that eagles can take-off faster and fly over the sky for long time and landing as faster as they can. From this observation, some parameter is investigated related to birds' performance and they found the parameter was wingspan, b.To be highlighted, according to Ajaj et al (2012)[3], large aspect ratio, AR has good range of flying but lack of maneuverability and low in cruise speed, opposite to low spans' wings. In military and civil, lots of morphing is applied on Unmanned Aerial Vehicles (UAVs) because of its low cost and risk to crew. Based on observations and researches that have been done before, so many efforts that must be done in order to optimize the aircraft functions, especially at wing configuration in order to minimize the drag and maximize the lift.In this task, the main point is to understand the purpose of bird's wing behavior during flying (close and open the wings) as effect to drag and lift forces. Secondly to understand the main point of the act as to apply to UAV. Lastly, to understand the effect of the behavior to flight performances.

2. Variable span morphing wing

As mentioned in title, my project is focus only on Variable Span Morphing Wing (as shown in Figure 2.6), wings that are connected to mechanism that can make the wingspan elongate or shorten from time to time in order to optimize aircraft performance over wider conditions' range. For small UAVs, this concept can be applied since many potential advantages offered by bio-inspired designs (Prabhakar, Prazenica & Gudmundsson, 2015) [2].

Span change is very important since it can change the AR of wings of aircraft and increase flight efficiency and/or flexibility. This change of AR give some effects on aircraft performances. For the straight wing, when the span, b is increase, the wing's area, A will increase. Since the AR is defined as square of span per unit area of wings, value of AR will increase when the s is increase, then the lift-to-drag ratio and also cruise distance will increase. Vice versa, when AR is decrease, drag will decrease while speed and Mach number will increase. The same thing happened to swept back wing. When the sweep angle is increase, the span, s will decrease while the surface area of wing, A remain the same, the result will be the same as span morphing wings.

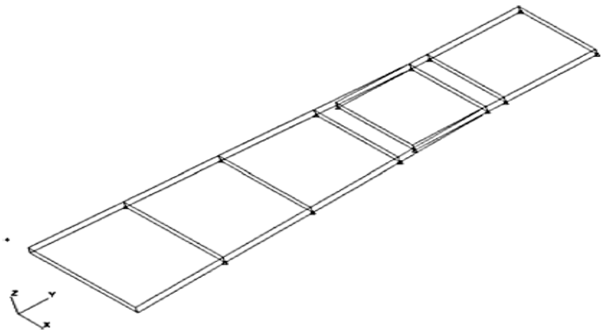


Fig. 2.1: Variable Span Wing.

This variable span morphing wing is a simple mechanical concept. Fixed wing (FW) will stay still at fuselage of aircraft, while outer moving wing (OMW) will stay at inner part of FW. A mechanism will be set up in FW to push the OMW out from FW in order to increase the span of wings. To apply this concept is not too easy. It is true that when the aircraft's wings is symmetry, the center of gravity (C.G) will not change, but with condition. During expanding of span wings, both OMW must expand or increase at the same rate, if not the surface area and half span will not same, as result will cause unbalance lift force on both wings of the aircraft. In previous study, Jha and Kudva introduced the servo motor with thread motor mechanism to be applied to span-morphing wings in order to solve this problem (Prabhakar, Prazenica & Gudmundsson, 2015) [2].

In another purpose, span morphing is useful to replace the ailerons to control the roll of aircraft. As stated above, different rate of increasing the wings' span for both sides of wings will give unbalanced lift force to wings. This unbalanced lift force will roll the aircraft. Roll of aircraft can be controlled by unsymmetrical span morphing (Ajaj et al, 2012) [3]. To create this asymmetric span morphing, right and left wings created separately and then mirrored so that each wing can set to be also controlled at different rates.

For military UAVs, this idea and concept is really suitable and attractive since they have to work and move at fast and effective rates at all condition, which means during taking-off and landing, they must do it in short time, while during cruising they must fly at long range but faster and also the rolling and others.

3. Ansys simulation method

Every single experiment and research must be done with the right or correct step or procedures. Because of that, the flowchart of project must be done. For my project, there are some steps in flow in order to obtain the better and accurate result (refer Figure 3.1).

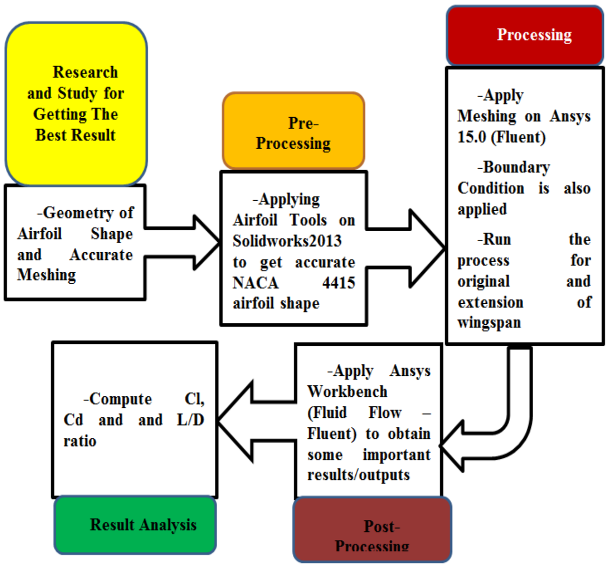


Fig. 3.1: Project Flowchart.

4. Numerical analysis

Numerical Analysis is study of algorithm that use in approximation for problems of mathematical analysis, which is to distinguish from discrete mathematics. This analysis method involves continuous variables. In this era, this analysis method is famous and been used widely especially for scientists and engineers in order to solve problem. With the help of computer (software) and technology, this method become easier to be applied.

5. Project development

According to previous studies, as reference, NACA 4415 is chosen to create the wings for UAV aircraft. NACA 4415 gives meaning; first digit '4' (maximum camber of 0.04c), second digit '4' (distance of leading edge, LE to maximum thickness of airfoil of 0.4c), last two (2) digits '15' (maximum wing thickness of 0.15c), where c is chord length. Every single coordinate is got from "Airfoil Tools" [5] website (shown in Figure 3.2) – 'selig format dat file' and been copied to Microsoft Excel to update the x-coordinates (column A) data from text to column. Column C is added with the values of non-zeros (Figure 3.3c). This non-zeros purpose is to make the airfoil model can be extruded to some values. Column B represents y-coordinates and column C represents z-coordinates. All z-coordinates is substituted as non-zeros for 2-dimensional airfoil. The data then is saved as 'Text (Tab delimited) (*.txt)'.

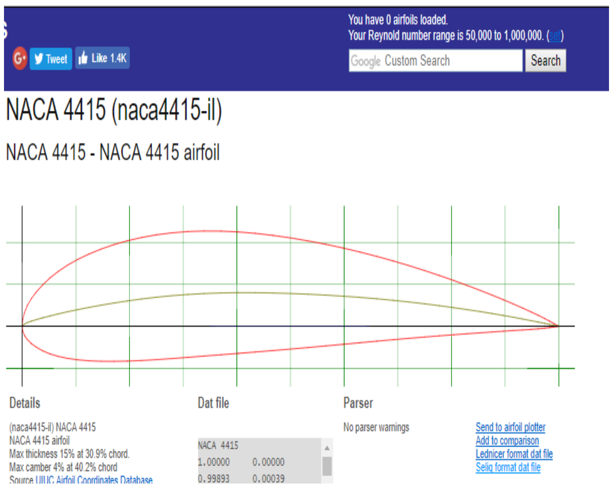


Fig. 3.2: Airfoil Tools (NACA 4415).

(A)

NACA 4415

1.000000	0.000000
0.998930	0.000390
0.995720	0.001560
0.990390	0.003490
0.982960	0.006100
0.973470	0.009320
0.961940	0.013030
0.948440	0.017160
0.933010	0.021660
0.915730	0.026520
0.896680	0.031710
0.875920	0.037170
0.853550	0.042830

(B)

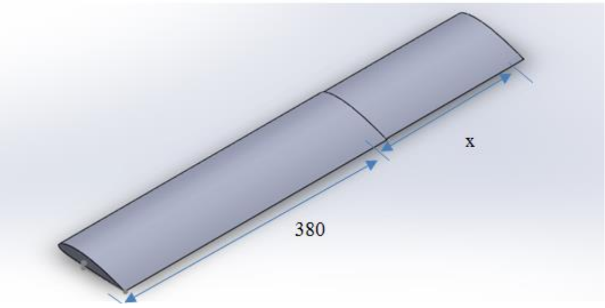
	A	B
1	1.000000	0.000000
2	0.998930	0.000390
3	0.995720	0.001560
4	0.990390	0.003490
5	0.982960	0.006100
6	0.973470	0.009320
7	0.961940	0.013030
8	0.948440	0.017160
9	0.933010	0.021660
10	0.915730	0.026520
11	0.896680	0.031710
12	0.875920	0.037170
13	0.853550	0.042830

(C)

	A	B	C
1	1	0	
2	0.99893	0.00039	
3	0.99572	0.00156	
4	0.99039	0.00349	
5	0.98296	0.0061	
6	0.97347	0.00932	
7	0.96194	0.01303	
8	0.94844	0.01716	
9	0.93301	0.02166	
10	0.91573	0.02652	
11	0.89668	0.03171	
12	0.87592	0.03717	
13	0.85355	0.04283	

Fig. 3.3: A) Original Data of NACA 4415 From Airfoil Tools Website B) Data Copied to Excel2013 C) Z-Coordinates Added Into Excel2013.

(A)



(B)

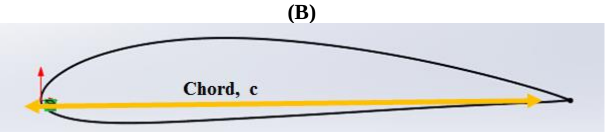


Fig. 3.4: Half Wing Dimension of NACA 4415 (AoA = 1°).

Extension percentage calculated as:

$$\text{Extension \%} = \frac{x}{284} \text{ x } 100\%$$

$$\text{Half wingspan, } \frac{b}{2} = 380 + x$$

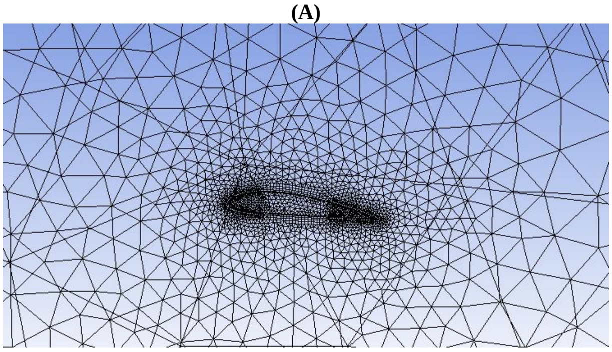
Fig. 3.5: Extension Formula.

The value of ‘x’ from 0% - 100% as follows: 0.00m, 0.0284m, 0.0568m, 0.0852m, 0.1135m, 0.1420m, 0.1704m, 0.1988m, 0.2272m, 0.2556m, and 0.2840m.

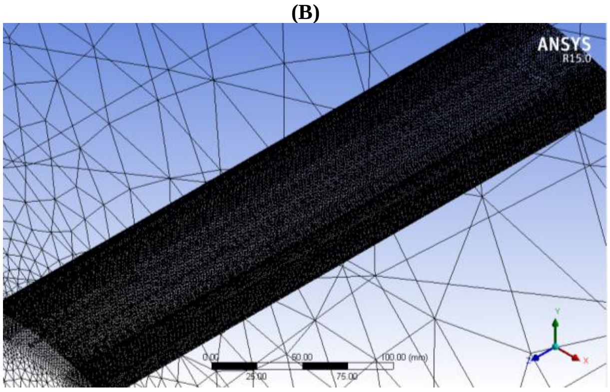
6. Processing (meshing)

Meshing is process to create fluid flow path in order to see the direction of fluid vector and others. It depends on from which side the fluid is computed. For this case the air is chosen as fluid and it is computed from the ‘Inlet’ of enclosure with inlet velocity of 75 m/s.

(A)



(B)



(C)

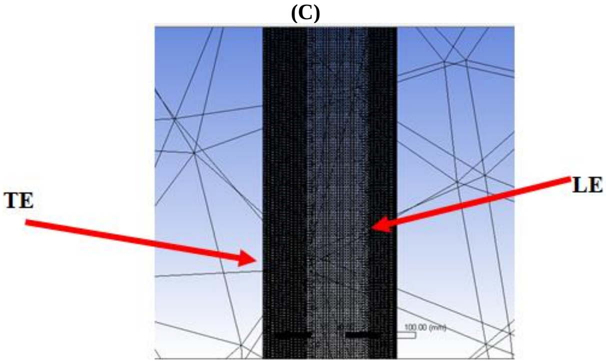


Fig. 3.6: Meshing A) Side View B) Isometric View C) Top View.

7. Boundary condition

Models: Viscous (Model: k-epsilon)
BC: Inlet (velocity magnitude: 75 m/s, turbulent intensity: 1%), Outlet (gauge pressure: 0 Pa)
Solution Initialization: Standard Initialization Method → Compute from Inlet, Reference frame (relative to cell zone) → Initialize.

8. Result and Discussion

Data Validation:

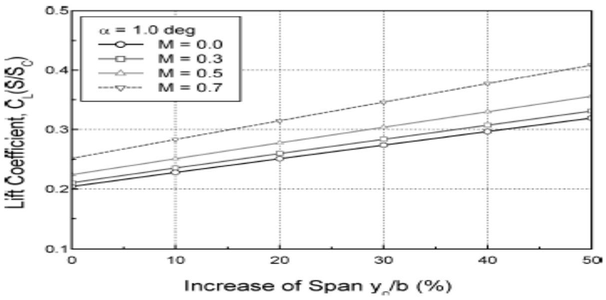


Fig. 8.1: Lift Coefficient to Wingspan Graph.

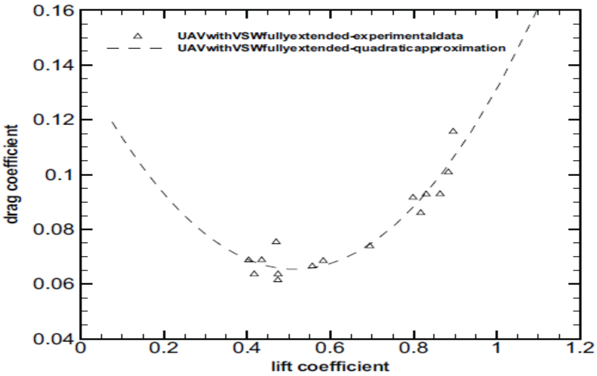


Fig. 8.2: Drag to Lift Coefficient Graph.

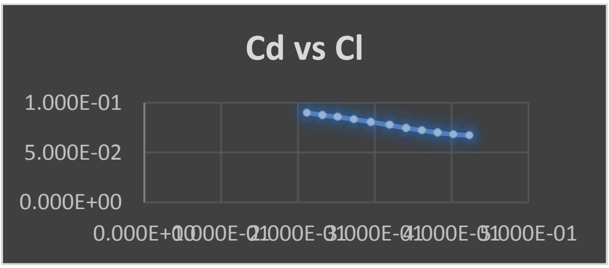


Fig. 8.3: Cd to Cl Graph.

From the iteration:

Table 8.1: Result

Wingspan (%)	wingspan/2 (mm)	Max. Face Area (mm2)	Aspect Ratio, AR	Max. Skewness	cl	cd	L/D
0	380.0	76656.52	3.77	0.8760	2.122E-01	8.983E-02	2.362E+00
10	408.4	82149.70	4.06	0.9734	2.321E-01	8.767E-02	2.648E+00
20	436.8	87643.59	4.35	0.9615	2.521E-01	8.564E-02	2.944E+00
30	465.2	93137.49	4.65	0.9346	2.732E-01	8.344E-02	3.274E+00
40	493.6	98626.40	4.94	0.9526	2.954E-01	8.066E-02	3.663E+00
50	522.0	104119.04	5.23	0.9406	3.195E-01	7.757E-02	4.119E+00
60	550.4	109611.69	5.53	0.9605	3.412E-01	7.455E-02	4.577E+00
70	578.8	115105.04	5.82	0.9648	3.614E-01	7.235E-02	4.996E+00
80	607.2	120596.99	6.11	0.9703	3.821E-01	6.988E-02	5.468E+00
90	635.6	126089.28	6.41	0.9612	4.026E-01	6.832E-02	5.892E+00
100	664.0	131582.28	6.70	0.9622	4.233E-01	6.721E-02	6.298E+00

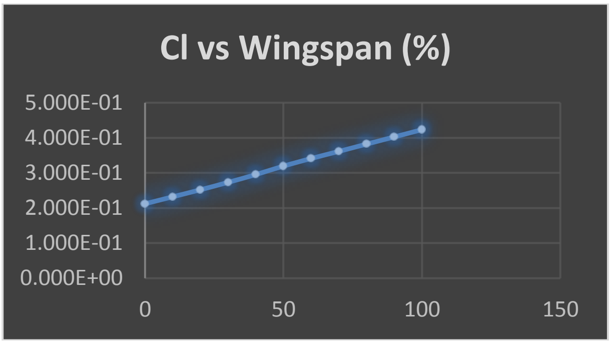


Fig. 8.4: Cl vs Wingspan Graph.

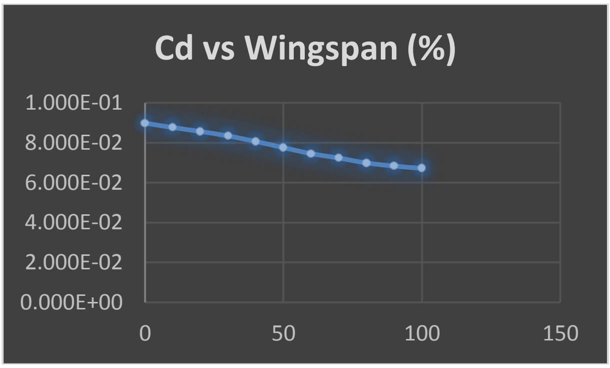


Fig. 8.5: Cd vs Wingspan Graph.

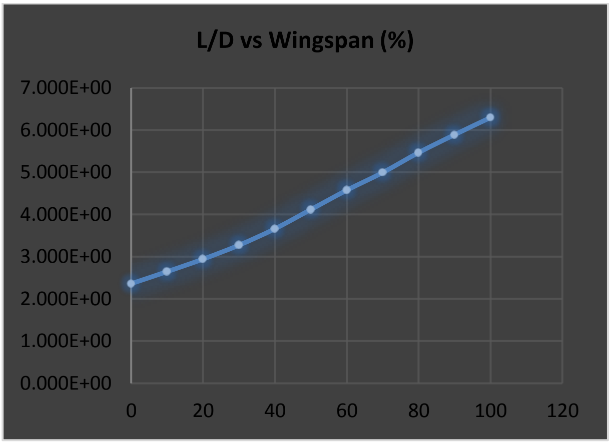


Fig. 8.6: L/D ratio vs Wingspan Graph.

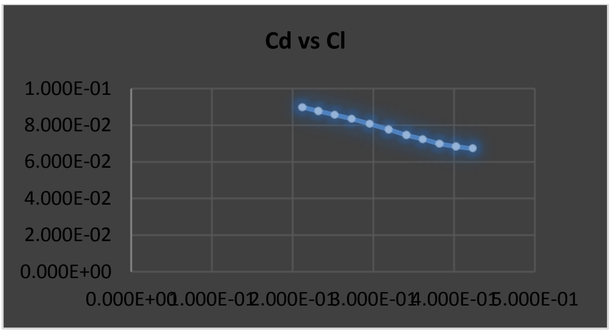


Fig. 3.7: Cd vs Cl Graph.

9. Discussion

In aviation and aerospace, especially for aircraft, there are some important and helpful parameter for aircraft performances. The two parameter are lift and drag forces/ coefficients. Lift force is the force against the weight. It depends on the lift coefficient and surface area of aircraft's wings. While drag force is the force against the thrust force and depends on drag coefficient. However both drag and lift forces depend on the velocity of aircraft itself.

In this study, as mentioned, everything must related to low Reynold flows (laminar flow). Laminar means there are no or almost no turbulent flow in the case. For laminar, also as mentioned before, velocity of aircraft V used is 75 m/s. In figure 4.25, velocity distribution around wingtip is observed. From the figure, at the trailing edge, since AOA used to run this project is 1o, there is a bit turbulent flow caused by air separation from wing surface. There is also a fact that the velocity of upper surface wing always higher than lower surface of wing. This can be related from Bernoulli Principle and been proved in the figure 4.26, which is the pressure of lower surface is always higher than its upper surface. At LE, it is normal to see there are the highest pressure for all wingtip since it is the first point the airstream attack the wing and also the LE surface is almost normal to airstream velocity. It is possible to say that at LE, weak normal shockwave produced, almost the same as nose of aircraft body.

From figure 4.28, vortex can be seen for all wing extension, caused by different air pressure at the lower and upper wing surface. Existing of vortex here also because of no wingtips at the wing end. For 0% extension, which is the first picture from the figure, the vortex produced is larger compared to other extension since the wingtip area of 0% is bigger compared to other wingtip areas.

From table 3.1, half wingspan, maximum face area is calculated by using Solidwork2013. While extension percentage and aspect ratio is calculated by calculator and the others are calculated by using Ansys. It is good to see almost meshing is good, which is less than 1.0 skewness. It is trouble to say if skewness statistic is more than 1.0 because the operation can cause turbulent and reversed flows. From figure 4.21, the result of lift coefficient Cl versus wingspan exntension is good enough. From theory, the longer the wingspan, the bigger the surface area, the higher the Cl. But, the opposite result happened to drag coefficient Cd in figure 4.22. When the surface area bigger, the Cd decrease. As mentioned, skewness statistic is so important. Some effort must be done in future for the detailed meshing so that the best result can be obtained.

In this report, there are no 30%, 40%, 50%, 60%, 70%, 80% and 90% since all these result almost the same as >10% as mentioned in figure 4.25 until figure 4.28.

At last, opposite to velocity profile, the pressure increase when the velocity profile decrease. In theory of basic velocity-pressure relationship by Daniel Bernoulli, when the velocity increases, the pressure will decrease.

10. Conclusion

In conclusion, the objective of this project have been achieved, even it is not too exact. The important parameter that gives the best effect on aircraft performances for lifting is wingspan, b. b is counted from the wingtip-to-wingtip of both aircraft's wings. This b give the result of new parameter which called as aspect ratio, AR. It is good to see the Cl increase when the b increase. From this result, we already know which is the best wing span for different phase that is going to be applied by UAV. However, future study must be done to increase this Cl up to almost 100 times of Cd increases. Impossible? Nothing impossible.

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